Initial in situ measurements of Perennial Meltwater storage in the Greenland firn Aquifer

Lora Koenig (Code 615)[1], Clement Miege[2], Richard Forster[2] and Ludovic Brucker (Code 615)[1,3]
[1]NASA Goddard Space Flight Center [2]University of Utah [3]Universities Space Research Association

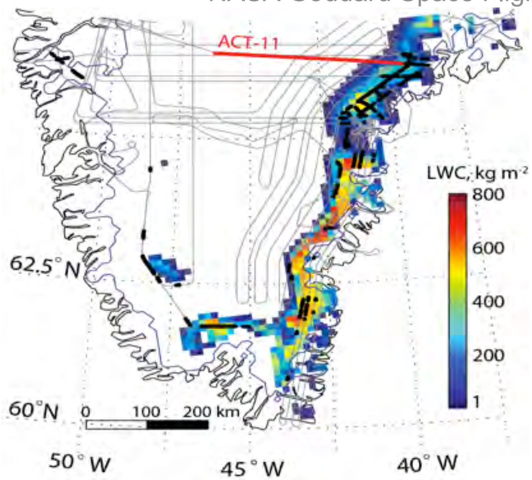


Figure 1: Map of Aquifer in Greenland. Black dots are Operation IceBridge (OIB) radar detections. Colors are liquid water content modeled by RACMO/2. Star is field site.

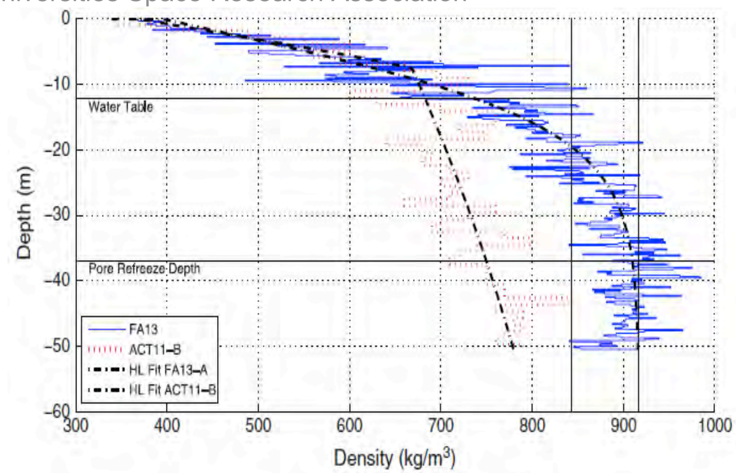


Figure 2: Density profiles from dry firn (red) and Aquifer site (blue) with fit lines (dashed) used to determine amount of stored water. The horizontal lines show the surface of the water table and the pore water refreeze depth or bottom.

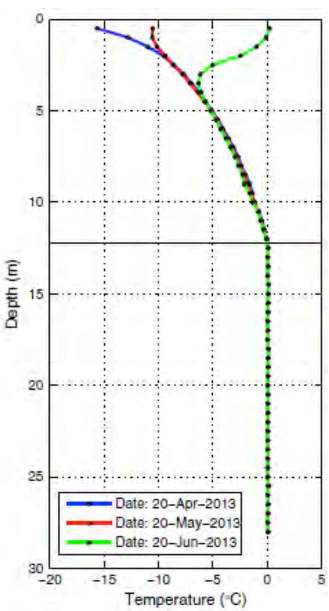


Figure 3: Aquifer temperature profile showing temperate ice (0°C).

Article featured on cover GRL V41(1)

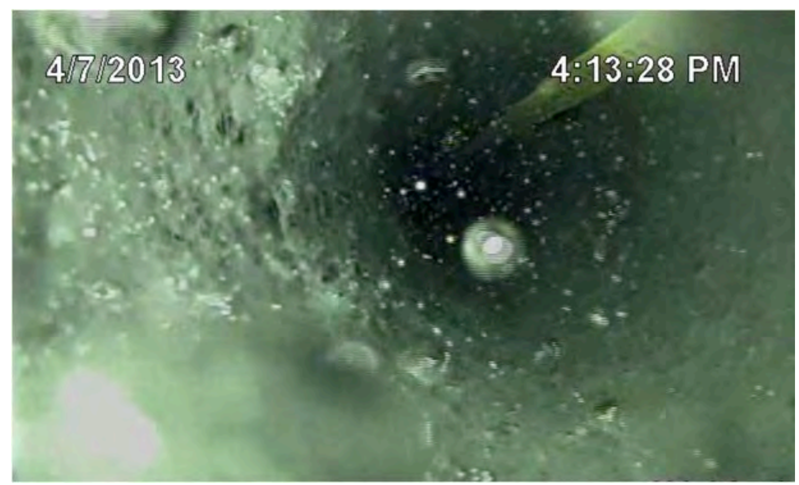


Figure 4: Image of water filled borehole from ~14 m deep into the Greenland Ice Sheet.

Name: Lora Koenig, Code 615
E-mail: lora.s.koenig@nasa.gov
Phone: 301-614-5507

Abstract: A perennial storage of water in a firn aquifer was discovered in southeast Greenland in 2011. The estimated stored water volume is 140 ± 20 Gt, representing ~0.4mm of sea level rise (SLR). This work presents the first in situ measurements of the aquifer, including densities and temperatures. It established the thickness of the stored water column at this location, 24.7 m, and estimated the volume estimate given above. The water storage capacity, the capacity for the firn pore space to store water temporarily mitigating SLR, was half full at this location.

References:

Koenig, L.S., C. Miège, R. Forster and L. Brucker (2014), Initial in situ measurements of perennial meltwater storage in the Greenland firn aquifer *Geophysical Research Letters 41(1), 81-85,* doi: 10.1002/2013GL058083.

Forster, R, J. Box, M. van den Broeke, C. Miège, E. Burgess, J. van Angelen, J. Lenaerts, L.S. Koenig, J. Paden, C. Lewis, S. P. Gogineni, C. Leuschen, and J. McConnell (2014), Perennial Liquid Water Discovered in Greenland Firn Layer. *Nature Geosciences,* doi: 10.1002/2013GL058083..

NASA web release: http://www.nasa.gov/content/goddard/enormous-aquifer-discovered-under-greenland-ice-sheet/#.Uz1n_VewV8E
Earth Observatory Blog:: http://earthobservatory.nasa.gov/blogs/fromthefield/category/greenland-aquifer-expedition/

Data Sources: Data is from field work conducted in 2013 and during the Arctic Circle Traverse in 2010, 2011. Other datasets used include Operation IceBridge Accumulation Radar and RACMO/2 model results.

Technical Description of Figures:
Figure 1: Map of Aquifer in Greenland. Black dots are OIB radar detections of aquifer. Colors are liquid water content modeled by RACMO/2 showing excellent agreement with measurements. Star is the 2013 field site where we took the first in situ measurements and drilled through the stored water column held in the aquifer.
Figure 2: Density profiles from dry firn (red) and Aquifer site (blue) with fit lines (dashed) used to determine amount of stored water. The horizontal lines show the surface of the water table and the pore water refreeze depth defined as the bottom of the aquifer.
Figure 3: Aquifer temperature profile showing temperate ice (0°C) throughout the stored water column, much warmer than previously modeled.
Figure 4: Image from borehole camera system of the water filled borehole from ~14 m deep into the Greenland Ice Sheet. Previous to these measurements meltwater percolation in this region was assumed to refreeze during the extremely cold winter months.

Scientific significance:
The discovery of the aquifer is the first direct evidence of a large storage of meltwater in the Greenland Ice Sheet that has the potential to delay, temporarily, some portion of melt contributing to SLR. Measurements also show the aquifer temperature remained at the melting point, representing a large heat reservoir within the firn that is not currently accounted for in ice dynamic models.

Relevance for future science and relationship to Decadal Survey:
The estimated stored water volume is 140 ± 20 Gt, representing ~0.4mm of SLR, however, it is unknown if the aquifer temporary buffers SLR through storage or contributes to SLR through drainage and/or ice dynamics. Future meltwater must continue filling the upper portion of the aquifer until either the firn is full, no longer allowing percolation of surface melt, forcing melt to flow directly to the ocean or a tipping point is reached where the stored water catastrophically releases. The processes controlling filling and drainage of the aquifer require future research to project future SLR contributions from the Greenland Ice Sheet.

South Pacific Bio-Optics Expedition 2014

Antonio Mannino, Code 616, NASA GSFC

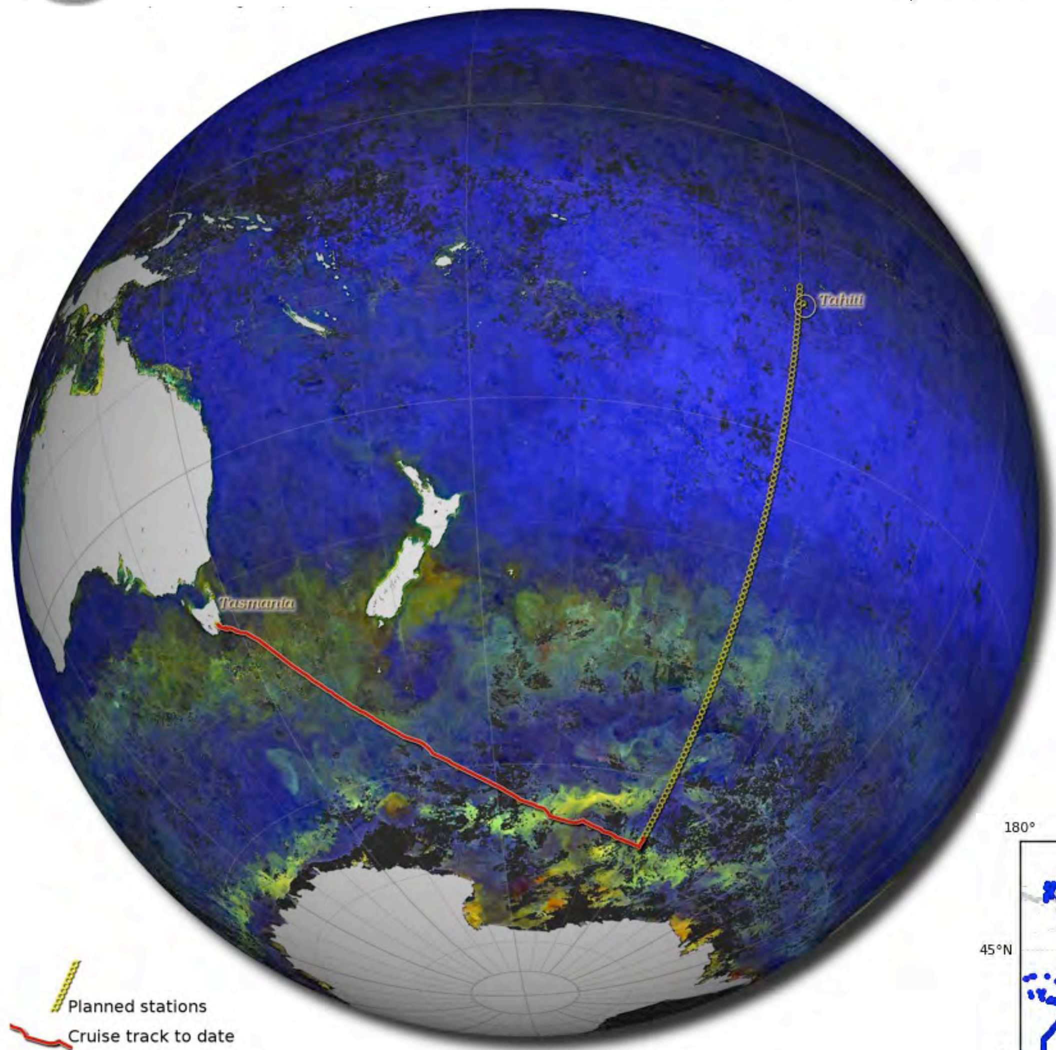


Figure 1: Cruise track of the Nathaniel B. Palmer as of April 1, 2014. This is a near-sided perspective projection of the Earth from an altitude of two Earth radii above 40 South by 175 West.

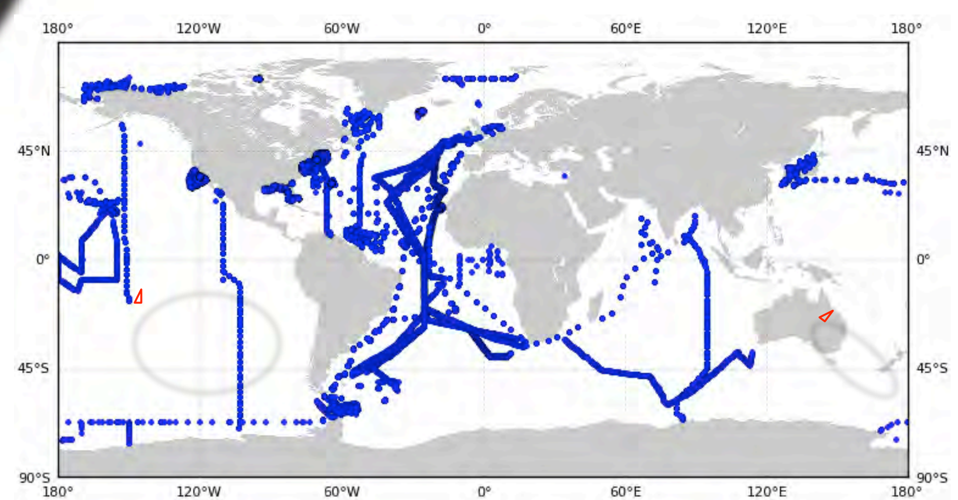


Figure 2: Map of SeaWiFS Bio-optical Archive and Storage System (SeaBASS) data holdings, including: Distribution of coincident Apparent Optical Properties (AOPs; water-leaving radiances), Inherent Optical Properties (IOPs; absorption and backscatter), and Chlorophyll a data.

Name: Antonio Mannino, NASA/GSFC/616; Aimee Neeley, NASA/GSFC/SSAI/616
E -mail: antonio.mannino@nasa.gov; aimee.neeley@nasa.gov
Phone: 301-286-0182; 301-614-5778

Abstract: Three members of the Ocean Ecology Laboratory's Field Support Group (FSG), Joaquin Chaves, Scott Freeman and Michael Novak, have deployed on a 45-day field campaign from Hobart, Tasmania to Pape'ete, Tahiti on the R/V Nathaniel B. Palmer. The FSG supports NASA's Ocean Biology and Biogeochemistry Program in the collection of complete optical and biogeochemical data sets for MODIS and VIIRS validation and in preparation for PACE. Their participation in the field campaign can be followed at http://earthobservatory.nasa.gov/blogs/fromthefield/. The oceanographic expedition is currently underway (March 21-May 5, 2014). Samples for analysis of phytoplankton pigments, particulate organic carbon, particle and dissolved absorption, phytoplankton taxonomy, and dissolved organic carbon will be collected and stored for analysis in the laboratory. Optical instruments will be deployed to collect vertical profiles of the upper ocean layer seen by ocean color satellite sensors (e.g. MODIS and VIIRS). A flow-through system will collect continuous optical and physical measurements during transit.

Technical Description of Images:
Figure 1: Cruise track of the Nathaniel B. Palmer as of April 1, 2014. This is a near-sided perspective projection of the Earth from an altitude of two Earth radii above 40 South by 175 West. Red line indicates ship track to date. Yellow circles indicate proposed ship track. The background image is a composite of remote sensing reflectances (Rrs) measured by Aqua-MODIS between 10 February 2014 and 13 March 2014. Red Channel: Rrs at 667 nanometers linearly scaled between 0.00002 and 0.00087. Green channel: Rrs at 547 nanometers linearly scaled between 0.001 and 0.00552. Blue channel: Rrs at 443 nanometers linearly scaled between 0.0019 and 0.0157. Image provided by Norman Kuring (Code 610.2) and will be updated daily during the remainder of the field campaign at http://oceancolor.gsfc.nasa.gov.

Figure 2: Distribution of coincident Apparent Optical Properties (AOPs; water-leaving radiances), Inherent Optical Properties (IOPs; absorption and backscatter, and Chlorophyll a data currently deposited into NASA's SeaWiFS Bio-optical Archive and Storage System (SeaBASS). Note the absence of bio-optical measurements in the South Pacific as indicated by the red ellipses. The map was provided by Chris Proctor (Code 616).

Scientific significance: The field campaign is part of US Repeat Hydrography, P16S, 2014 under the auspices of GO-SHIP and sponsored by the US Climate Variability and Predictability Program (CLIVAR).
Vertical profiles include measurements of Apparent and Inherent Optical Properties (hyperspectral UV-Vis-NIR downwelling irradiance and upwelling radiances; AOPs). IOPs include measurements of a_{pg} (particle and dissolved absorption), c_{pg} (particle and dissolved attenuation), a_g (dissolved absorption),c_g (dissolved beam attenuation), temperature, salinity, scattering at 3 angles, 660 nm, chlorophyll and CDOM fluorometry using . In addition, for approximately 30 days, staff will obtain profiles of a_{pg}, c_{pg}, a_g, c_g, scattering at 9 angles and 9 wavelengths, temperature and salinity, *L*u (upwelling radiance), *E*d (downwelling irradiance), and *E*s (surface irradiance). These data will eventually be ingested into NASA's SeaWiFS Bio-optical Archive and Storage System (SeaBASS) and subsequently used for ocean color satellite validation activities.

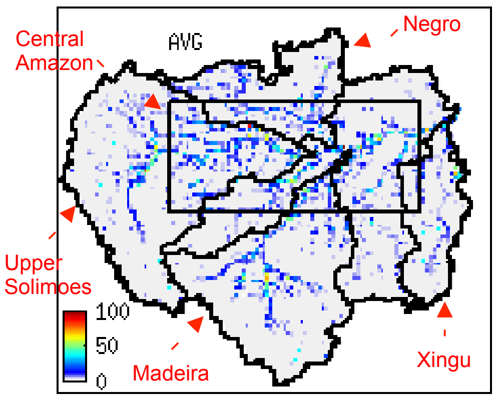
Relevance for future science and relationship to Decadal Survey: Ocean field data, in particular Lu, Ed, Es and IOPs, necessary for ground-truthing ocean color satellite-derived products are sparse in many regions of the global Ocean. The FSG will travel over much of the South Pacific during this field campaign and collect the desired bio-optical data to fill in this data gap. Complete optical and biogeochemical data sets are principal components of algorithm development for current and future missions such as PACE.

Team Members: Joaquin Chaves, Scott Freeman, Karen Mitchell, Michael Novak

Floods in the Amazon basin from HyMAP and multi-satellite products

Augusto C.V. Getirana, NPP/Code 617

Inundation extent
Multi-LSM



Satellite

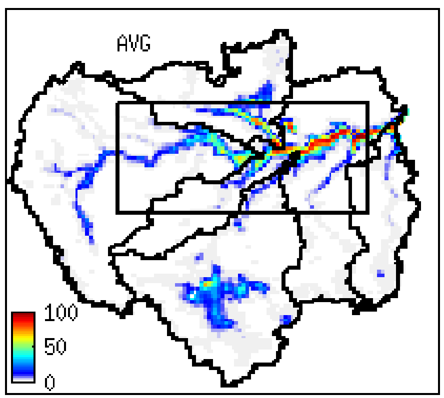


Figure 1: Inundation extent from HyMAP (top) and multi-satellite estimates (bottom) averaged for the 1993-2007 period. HyMAP results correspond to the average of 14 runs forced with multi-LSM outputs.

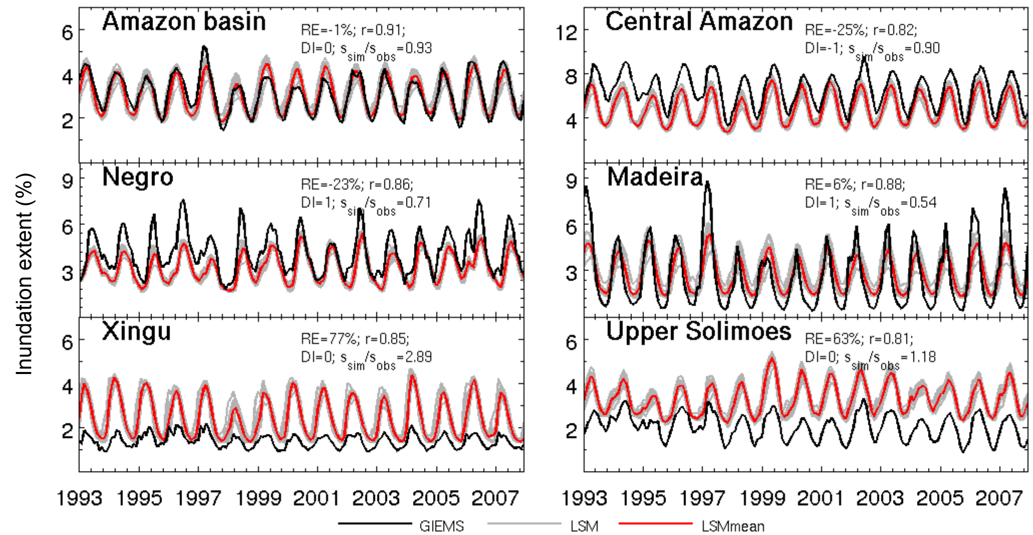


Figure 2: Monthly inundation extent time series from HyMAP simulations forced with multi-LSM outputs and GIEMS estimates. The six locations are defined in Figure 1.

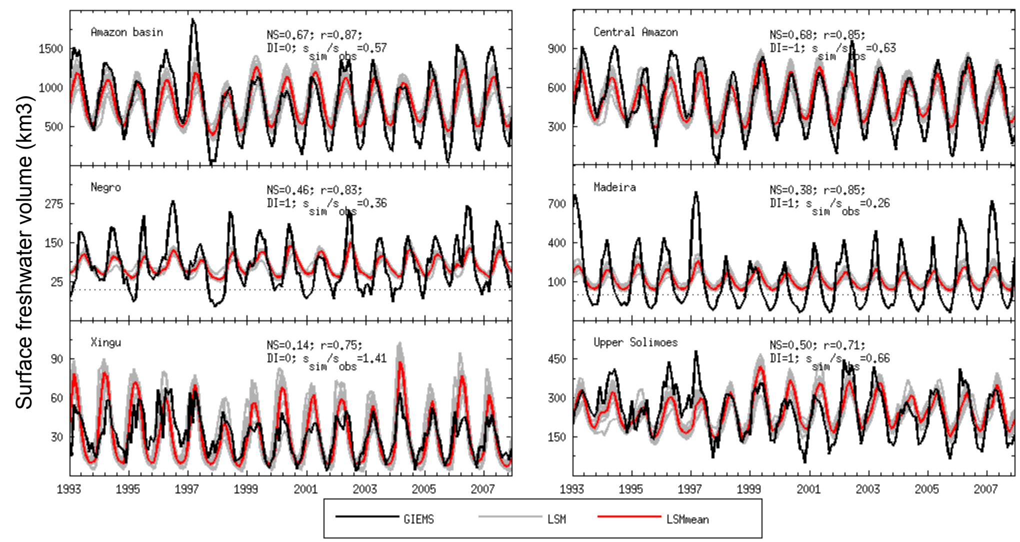


Figure 3: Surface freshwater volume time series from HyMAP simulations forced with multi-LSM outputs and GIEMS estimates combined with ASTER DEM. Satellite estimates were corrected with the mean values of LSM time series. The six locations are defined in Figure 1.

Name: Augusto Getirana, NPP/ORAU, NASA/GSFC, Code 617
E-mail: augusto.getirana@nasa.gov
Phone: 301-614-5783

Abstract: Accurate simulations of surface freshwater dynamics are essential to improve flood forecasts, biochemical processes in floodplains and to better understand its interactions with the atmosphere, land cover and groundwater. In this study, surface freshwater dynamics over the Amazon basin is evaluated by means of floodplain extent and the surface freshwater storage. The physical processes were simulated by the Hydrological Modeling and Analysis Platform (HyMAP) forced with outputs from a land surface model (LSM) ensemble and compared against satellite-based estimates at the monthly time step. The experiment was performed during the 1993-2007 period.

References:

Getirana, A.C.V., Boone, A., Yamazaki, D., Decharme, B., Papa, F., Mognard, N., 2012. The Hydrological Modeling and Analysis Platform (HyMAP): evaluation in the Amazon basin Journal of Hydrometeorology 13, 1641–1665. DOI: 10.1175/JHM-D-12-021.1.
Getirana, A.C.V. et al., 2014. Water balance in the Amazon basin from a land surface model ensemble, Journal of Hydrometeorology, in review.
Papa, F., Frappart, F., Güntner, A., Prigent, C., Aires, F., Getirana, A.C.V., Maurer, R., 2013. Surface freshwater storage and variability in the Amazon basin from multi-satellite observations, 1993–2007. Journal of Geophysical Research, 118, 11,951–11,965, doi:10.1002/2013JD020500.

Data Sources: The HyMAP river routing scheme (RRS) has been forced with multi-LSM outputs [see Getirana et al. (2014) for list of models]. Water budget simulations have been performed using the meteorological dataset provided by the Princeton University on a 3-hourly time step and at a 1° resolution and corrected monthly with the HyBAM precipitation dataset. Surface freshwater dynamics has been compared against the Global Inundation Extent from Multi-Satellite (GIEMS) and surface water storage estimates derived from the combination of GIEMS and the Advance Spaceborne Thermal Emission and Reflection Radiometer (ASTER) digital elevation model (DEM), as described in Papa et al. (2013).

Technical Description of Figures:

Figure 1: Inundation extent from HyMAP (left) and multi-satellite estimates (right) averaged (AVG) for the 1993-2007 period. HyMAP results correspond to the average of 14 runs forced with multi-LSM outputs.
Figure 2: Monthly inundation extent time series from HyMAP simulations forced with multi-LSM outputs and GIEMS estimates. The six locations are defined in Figure 1.
Figure 3: Surface freshwater volume time series from HyMAP simulations forced with multi-LSM outputs and GIEMS estimates combined with ASTER DEM. Satellite estimates were corrected with the mean values of respective LSM time series. The six locations are defined in Figure 1.

Scientific significance:
Surface freshwater dynamics and its interactions with the atmosphere and groundwater are poorly represented absent in most state-of-the-art atmospheric models. These processes can impact local and regional weather and its inclusion in a fully coupled system can improve forecasts. The main contribution of this study is the quantification of how the uncertainty from water budget simulated by LSMs is propagated to river routing schemes. It also provides guidance to better identify limitations of river routing scheme parameters, specially those representing river and floodplain geometry.

Relevance for future science and relationship to Decadal Survey:
Identifying and reducing uncertainties in RRS parameterizations will enable us to improve surface freshwater simulations, and multi-satellite products can be used in this process. Reliable simulations of the surface freshwater are key for evaluating its impacts on groundwater and atmosphere and to better understand biochemical dynamics. It is also important for flood monitoring and forecasts. Data from the future SWOT mission will be essential in the improvement of RRS parameters by providing a better mapping of floodplains and water storage change over the continents.

Surface freshwater dynamics within the LIS-HyMAP coupled system

Augusto C.V. Getirana, NPP/Code 617 Sujay V. Kumar, SAIC/Code 617, GSFC

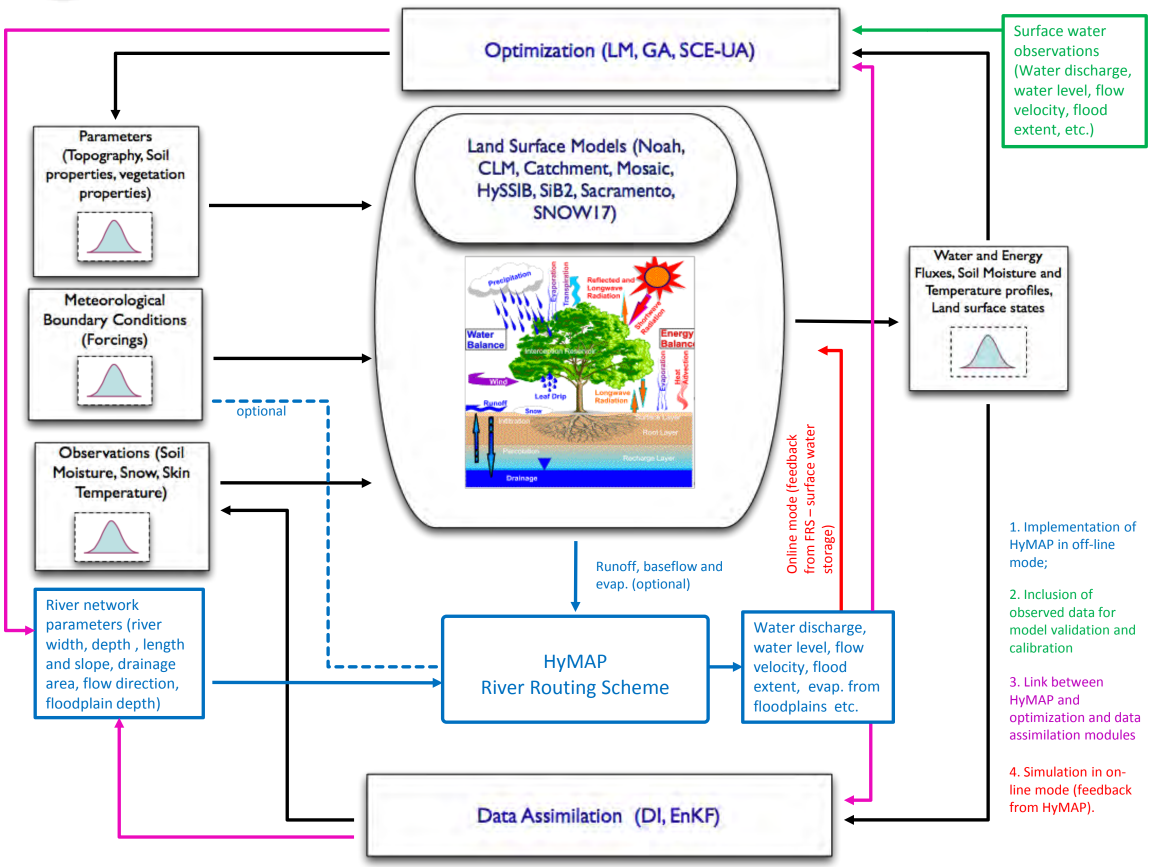
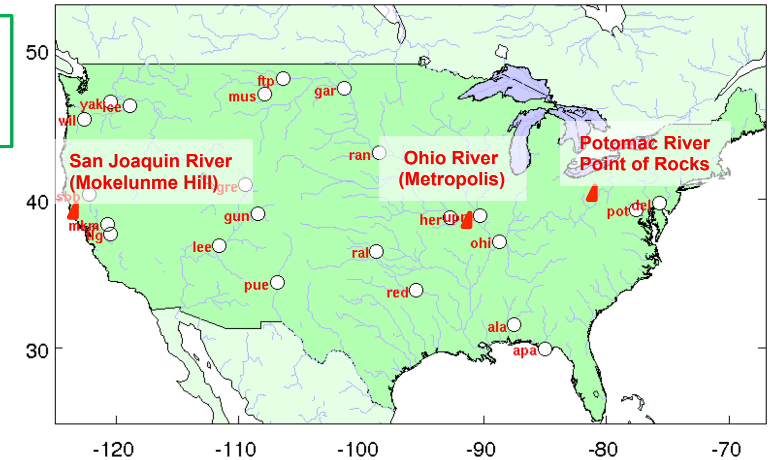


Figure 1: Schematic of the LIS-HyMAP coupled system and future implementations (LIS-HyMAP-DA and LIS-HyMAP-Optimization).



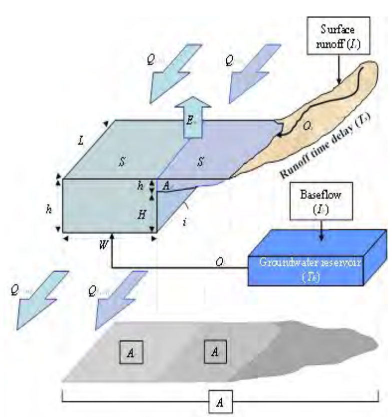


Figure 2: Schematic of HyMAP and its surface freshwater physical processes.

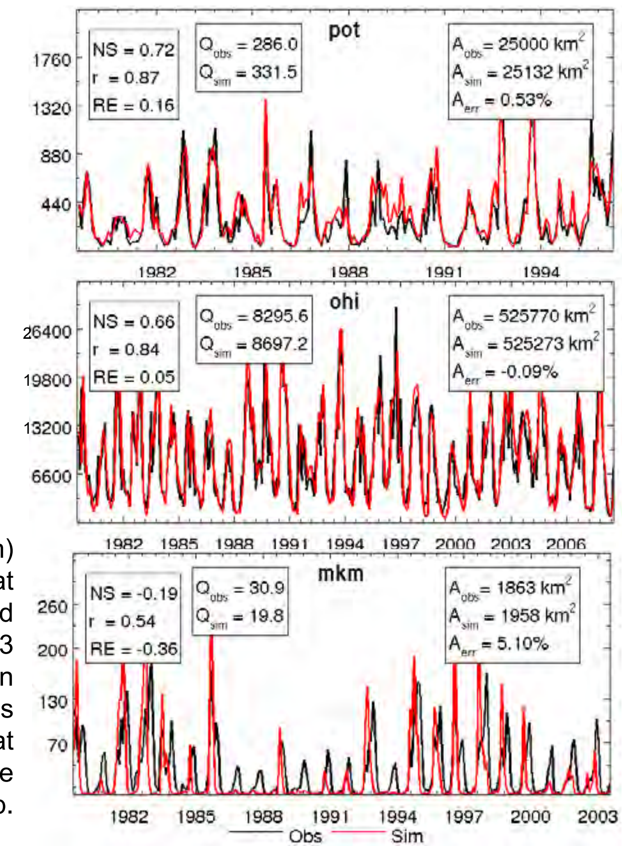


Figure 3: Monthly simulated (sim) and observed (obs) streamflow at three gauging stations located within the CONUS using Noah3.3 outputs forced with Princeton meteorological dataset. In this experiment, HyMAP was run at 0.25-degrees and 15-min time step.

Name: Augusto Getirana, NPP/ORAU, NASA/GSFC, Code 617
E-mail: augusto.getirana@nasa.gov
Phone: 301-614-5783

Abstract: In the last decades, river routing schemes (RRS) have shown their utility in providing us a better understanding of the hydrological processes at different spatial and temporal resolutions by simulating surface freshwater dynamics over the continents. Such models can also be used for flood forecasts, evaluation of water availability of water for engineering projects, water resources management, multiple water use, among others. Ultimately, physical processes can be more accurately represented by fully coupling RRS with land surface models (LSMs), i.e. representation of interactions among surface freshwater, groundwater and atmosphere. This work presents the recent implementation of the Hydrological Modeling and Analysis Platform (HyMAP) in the Land Information System (LIS). LIS users are now able to run HyMAP either simultaneously with any LSM available in LIS or alone using LSM outputs. The LIS-HyMAP system can be run at the global scale with flexible spatial and temporal resolutions.

References:

Getirana, A.C.V., Boone, A., Yamazaki, D., Decharme, B., Papa, F., Mognard, N., 2012. The Hydrological Modeling and Analysis Platform (HyMAP): evaluation in the Amazon basin Journal of Hydrometeorology 13, 1641–1665. DOI: 10.1175/JHM-D-12-021.1.
Kumar, S.V., Peters-Lidard, C.D., Tian, Y., et al., 2006. Land information system: An interoperable framework for high resolution land surface modeling. Environmental Modelling & Software 21, 1402-1415. doi:10.1016/j.envsoft.2005.07.004

Data Sources: LIS platform and HyMAP river routing scheme.

Technical Description of Figures:

Figure 1: Schematic of the LIS-HyMAP coupled system and future implementations (LIS-HyMAP-DA and LIS-HyMAP-Optimization).
Figure 2: Schematic of HyMAP and its surface freshwater physical processes.
Figure 3: Monthly simulated (sim) and observed (obs) streamflow at three gauging stations located within the CONUS using Noah3.3 outputs forced with Princeton meteorological dataset. In this experiment, HyMAP was run at 0.25-degrees and 15-min time step.

Scientific significance:
The implementation of HyMAP in LIS allows one to simulate simultaneously the vertical energy and water balance and the horizontal water fluxes. HyMAP provides physically-based simulations of surface freshwater dynamics, including flow velocity, water discharge and levels in both rivers and floodplains, water surface extent, among others. This implementation has been useful for the evaluation of meteorological forcings and water balance simulated by LSMs, as well as the assessment of soil moisture data assimilation (DA) impacts on water discharges.

Relevance for future science and relationship to Decadal Survey:
Implementing HyMAP in LIS is the first step towards a full representation of interactions between surface freshwater, groundwater and atmosphere using a large range of LSMs available in the system. Also, combining HyMAP and the range of DA and optimization schemes found in LIS will facilitate the integration of current (JASON-2) and future (SWOT) NASA altimetry data into a flood monitoring and forecast framework.

Stereo IKONOS is a viable tool for measuring forest canopy height

Christopher Neigh, Jeffrey Masek & Bruce Cook, Code 618, NASA GSFC

Forest carbon is a critical and poorly understood component of the carbon cycle, and is related to forest height. Accuracy of results achieved are comparable to best available height measurements of forest canopies from space.

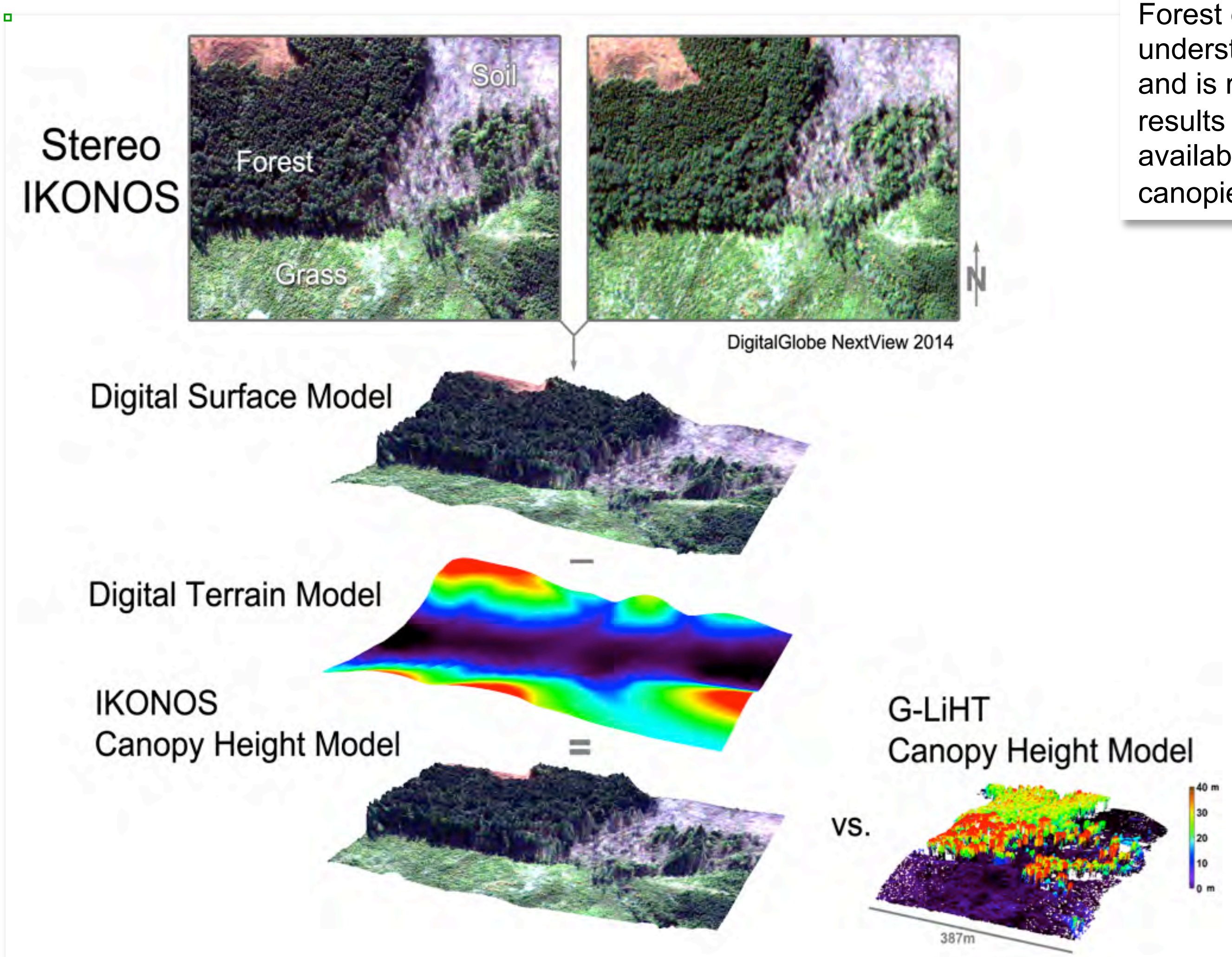


Figure 1. Methods for generating canopy height models from stereo IKONOS imagery. We compared canopy height models between IKONOS and LiDAR from G-LiHT which served as truth to evaluate the accuracy of high-resolution imagery for mapping forest canopy height.

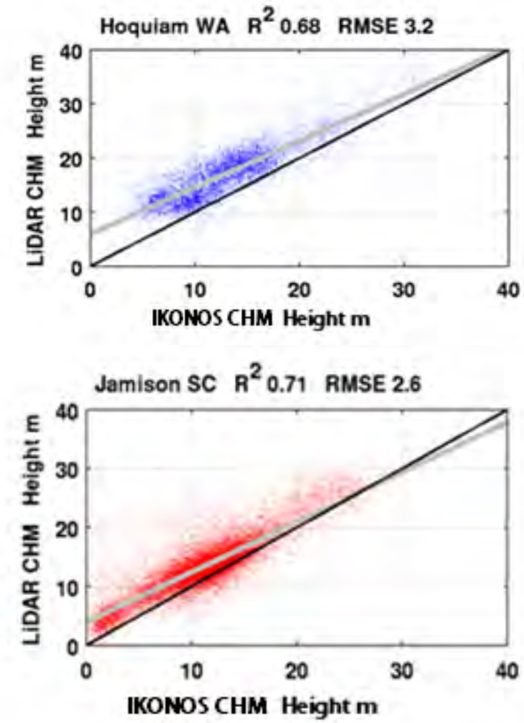


Figure 2. Results of comparison between G-LiHT canopy height models (CHMs) and IKONOS CHMs in two regions of the US.

Name: Christopher Rudasill-Neigh, NASA/GSFC
E-mail: Christopher.S.Neigh@nasa.gov
Phone: 301-614-6681

Abstract: Forests account for a majority of the aboveground carbon stock, but large uncertainties about its distribution remain. We compared forest height, a proxy for carbon density, from airborne LiDAR recognized as truth, to 1 m commercial stereo IKONOS imagery that is widely available. Physically meaningful forest structure information can be retrieved from IKONOS stereo imagery and height estimates are correlated to airborne LiDAR.

References:

2014 Neigh C.S.R., Masek J., Bourget P., Cook B., Huang C., Rishmawi K., and Zhao F. Deciphering the precision of stereo IKONOS canopy height models for U.S. forests with G-LiHT airborne LiDAR. *Remote Sensing*, 6 1762-1782. 10.3390/rs6031762

2013 Neigh C.S.R., Masek J., and Nickeson J. High Resolution Satellite Data Open to Government Scientists. *AGU EOS Transactions* 94 (13), 121-123. 10.1002/2013EO130002

Data Sources:
The analysis was performed as part of the North American Forest Dynamics (NAFD) project, a NASA-funded investigation to improve characterization of US forest disturbance patterns in support of the North American Carbon Program (PI: Samuel Goward, University of Maryland; GSFC CO-I: Jeffrey Masek, Code 618 NASA GSFC). IKONOS imagery were collected fro m the National Geospatial Intelligence Agency (NGA) under the NextView license agreement with DigitalGlobe and Goddard's LiDAR Hyperspectral and Thermal Imager, (G-LiHT) airborne LiDAR data were collected as part of a the AMIGA-Carb project which is another NASA funded investigation.

Technical Description of Images:

Figure 1. A 3-D graphical description of how canopy height models (CHMs) were created from Stereo IKONOS imagery near Hoquaim WA. True color pan-sharpened IKONOS imagery was subset to show details of forest structure. (top) Left and right within track 1 m resolution stereo IKONOS data were processed calculating image parallax to extract a digital surface model (DSM). (middle) A digital terrain model (DTM) derived from the national elevation (NED) dataset was then subtracted from the DSM to produce CHMs which is an estimate of canopy height with no terrain. We compared CHMs between IKONOS and Goddard's LiDAR Hyperspectral and Thermal Airborne Imager (G-LiHT) which acted as truth.

Figure 2. Scatter plot results showing a random sample of pixels between G-LiHT CHMs and IKONOS CHMs.

Scientific significance:
The spatial distribution of aboveground forest carbon is poorly known over many areas of the globe. Estimates of forest carbon are required for accurate prediction and modeling of changes in carbon sinks and sources. This work is the one of the first to demonstrate that high-resolution commercial stereo imagery provides highly accurate forest structure in different ecoregions. Combining these data with models one could to infer total aboveground carbon stock.

Relevance for future science and relationship to Decadal Survey:
Forest carbon is a critical component of the carbon cycle, and is sensitive to climate change and disturbances. Forest structure observations from high-resolution commercial instruments are available at no direct cost through the National Geo-spatial Intelligence Agency (NGA) NextView license agreement with DigitalGlobe. Combining these data with Landsat disturbance history, airborne and field measurements, one could provide the necessary data products to infer aboveground carbon stock in forests worldwide. Current work has been extended to study the taiga-tundra transition zone to establish a baseline extent of the northern forest limit.